INFLUENCE OF SOME WINDING PARAMETERS ON HAIRINESS OF YARN AFTER WINDING PROCESS

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ABSTRACT

Hairiness is an important quality parameter of yarn after winding process. It affects not only the quality of yarn, but also the productivity of the warping, weaving, knitting machines as well as the quality of produced fabrics. Hairiness is influenced by the factors of raw materials, technology and equipment at all stages of yarn production. This article presents the results of experimental research on the simultaneous influence of four typical winding parameters, including: Winding speed (Z_1), the load on the friction discs of the yarn tensioner (Z_2), the distance between the bobbin and the yarn guide (Z_3) and the pressure of package on the grooved drum (Z_4) to the increasing percentage of the hairiness of the yarns after winding compared to that before winding. Yarn hairiness was measured by Uster tester 5. By using the second-order orthogonal experimental planning, together with the support of Excel 2019 and Design Expert 11 software, an experimental matrix and mathematical models describing the relationship between the four winding parameters and increasing percentage of the hairiness of three types of yarn (carded Ne 31/1 CVCD, combed Ne 30/1 CVCM, combed Ne 30/1 COCM) are established. The research result is the scientific basis for selecting the optimal winding parameters in order to achieve the required increase in hairiness of the yarn after winding or predict hairiness increase of the yarns before winding.

KEYWORDS

Winding; Winding parameters; Yarn hairiness; Hairiness measurement.

INTRODUCTION

The ends of the fibers, the very small loops of yarn protruding from the surface of the yarn, cause the yarn hairiness. In fact, especially when spinning from short fibers such as cotton... it is inevitable that the yarn will have hairiness. High yarn hairiness increases the breakage rate of yarn on winding, warping, weaving and knitting machines. Depending on the use of the yarn, the hairiness requirement of the yarn will change. Products of sewing thread, woven fabric, and knitted fabric need to clearly show the weaving pattern, beautiful surface, and very little hairiness of the yarns. In contrast, for the production of napped fabric or felt fabric, yarns with high hairiness are needed to form a good layer of snow on the surface of the fabrics.

Hairiness is expressed in a variety of ways including the number of protruding fiber ends per unit of the length of yarn (usually 1m), the average length of the fiber ends, the total length of the fiber ends, the total area of the fiber ends. Of all, the expression of hairiness by the number of protruding fiber ends has been widely applied. Currently, the hairiness of a 1000m yarn test sample is understood as the average value of the length of the ends protruding from the main connection of the yarn body in one unit length of one centimeter [1].

The level of hairiness is affected by the properties of the raw material, yarn parameters, and processing parameters. Here, only a few studies on the influence of winding technology on yarn properties including hairiness are mentioned.

Zhigang Xia et al [2] studied the effect of repeated winding on carded ring cotton yarn properties, including hairiness, winding speed at 840m/min, the load applied to the friction discs of the tensioner is 45g. According to this study, the yarn after winding had a yarn count decrease in T (tex) due to partial loss of the yarn mass. Unevenness U% and imperfection index (IPI) (thin (-50%), thick (+50%), neps (+200%)) are improved, breaking strength as well as breaking work declines. The hairiness was measured by the YG172 hairiness meter. This study also shows that hairiness of all yarns is largely increased after windings, total yarn hairs per 10 meters increase and the largest increasing percentage of the hairiness are almost designated to the hairs ranged in the length from 2 to 4mm.

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Received November 4, 2022; accepted December 9, 2022

MD Zahidul Islan [3] studied the effect of winding speed on the properties of the yarn after winding. In this work, two yarns of Ne 22 carded hosiery and Ne 22 combed hosiery were wounded in Autoconer winding Machine at the speed of 1400m/min, 1500m/min and 1600m/min. The research results showed that the parameters U%, IPI, hairiness H of the yarn after winding increased with the winding speed respectively. When winding at the speed of 1600m/min, U% of the yarn after winding increased by 17%, the IPI increased by 43.03%, the H increased by 40% compared to before winding, while with the Ne 22 carded cotton yarn, U% of the yarn after winding increased by 21.7%, the IPI increased by 47.6%, the H increased by 48.5% compared to before winding. The level of U%, IPI, H% of the carded yarn is higher than that of the combed yarn with the same Ne 22.

According to R. Senthil Kumar [4], in the case of winding from a bobbin, the parameters of the yarn after winding increase at the average level as follows: U% = 3 ÷ 5%, Thin (-50%): 0 ÷ 0.5%, Thick (+50%): 15 ÷ 20%, Neps (+200%): 5 ÷ 10%, hairiness H = 25 ÷ 30% is acceptable. However, to achieve the above increases, it is necessary to wind with reasonable parameters to be able to achieve.

Jun Lang and Sukang Zhu [5,6] investigated the hairiness change of yarn during winding by analyzing forces acting on the fiber ends protruding from the yarn body. According to this study, the cause of yarn hairiness is due to the yarn's friction with the friction discs of the tensioner and the grooved drum of the winding machine. This is a theoretical study, the established equations of the effects of the tension disks and the grooved drum on the yarn hairiness contain many unknowns (coefficients), so it is difficult to apply this research in practice.

Rafael Beltran et al [7] established a winding model in which an air nozzle was positioned between the tensioner and the grooved drum. The air pressure in the nozzle is 0.7 bar. Research results have shown that, when equipped with an air nozzle on the motion trajectory of the yarn, the hairiness of the yarn (the number of fiber ends with a length of 3mm) was reduced by 33% compared to when there was no air nozzle.

Noman Haleen and Tungai Wang [8] summarized and developed the research on hairiness. In this study, the authors summarized the methods of measuring hairiness, material factors, and technology (mainly in the pre-winding stages) affecting hairiness. According to this study, over 600 research studies directly or indirectly related to hairiness have been reported proving that hairiness is very interesting.

It can be seen that the properties of the yarn after winding have changed compared to before winding [9, 10], in which the hairiness increases sharply with the winding speed. In fact, the hairiness of the yarn after winding not only influenced by the winding speed, but also by many other winding parameters such as the load placed on friction discs of the tensioner, the position of the bobbin, the pressure of the package on the grooved drum... these parameters also affect yarn tension and also affect hairiness but have not been studied.

Thus, in order to achieve the yarn hairiness or hairiness increase of the yarn after winding, it is necessary to study the simultaneous influence of some typical winding parameters on the hairiness of the yarn, establishing mathematical models showing the relationship between the increase in yarn hairiness after winding and some typical winding parameters creating a scientific basis to select the optimal winding parameters to achieve the required hairiness of the yarn. This is a topical issue that interests the enterprises producing and using yarn after winding, because the hairiness of the yarn is not only related to the quality of textile products but also related to the cost of yarn in the market.

MATERIAL AND METHODS

Materials

Three types of ring yarns: Ne 31/1 CVCD (Carded yarn Ne 31/1 60% Cotton 40% Polyester); Ne 30/1 CVCM (Combed yarn Ne 30/1 60% Cotton 40% Polyester); Ne 30/1 COCM (Combed yarn Ne 30/1 100% Cotton) were wound on the same kind of bobbin produced by Vinatex Nam Dinh factory in Vietnam (Table 1). These are also 3 types of yarns being produced by many spinning mills in Vietnam to export to China. Procedure for selecting test samples according to ASTM D 2258-99 Standard Practice for sampling yarn for testing. Each winding was conducted for 2 minutes to ensure the same yarn length on the package and enough yarn length to test the yarn hairiness.

Methods

The winding model

The winding model is developed in Hanoi University of Science and Technology has the principle diagram in Figure 1.

Yarn 10 is removed from the bobbin 9, through the yarn guide 11, yarn tensioner 12, yarn clearer 13, yarn guide 14, grooved drum 7 and then wound on the package 8.

Table 1. The parameters of three types of yarns.

Parameters	Yarn 31/1CVCD	Yarn 30/1CVCM	Yarn 30/1COCM
Type of yarn	***Carded (60% cotton, 40% polyester)***	***Combed (60% cotton ,40% polyester)***	***Combed (100% Cotton)***
Yarn count [hank/pound]	31/1	30/1	30/1
Yarn twist [t/m]	760	744	766
Breaking Force [cN]	284.7	289.7	277.8
Elongation [%]	6.2	6.25	4.44
Tenacity [cN/tex]	15.04	14.91	14.34
Hairiness	5.61	5.55	5.7
Unevenness U [%]	11.01	9.44	8.94

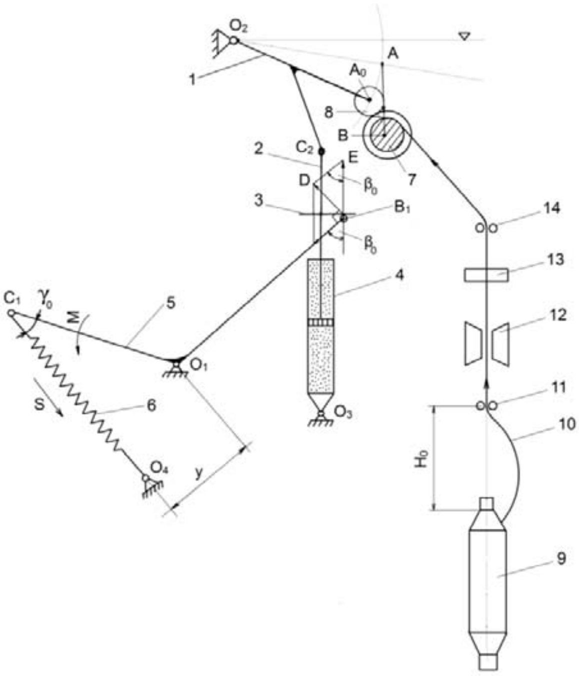

Figure 1. Principle diagram of the winding model.

Short branch of the package holder 1 connected to piston rod 2 moving in cylinder containing air (oil) 4. One end of lever 5 rests on stop plate 3 fastened on the piston rod, the other end of this lever is connected to spring 6. Details 2, 3, 4, 5, 6 create a mechanism to balance the pressure of the package on the grooved drum. With such a structure, when the diameter (mass) of package 8 increases, lever 1 will have to rotate counter-clockwise around O_2, lever 5 will rotate counter-clockwise around O_1, pulling force S of spring 6 will decrease but the distance y from spring to O_1 increases to compensate, force D at B_1 remains constant because moment M considering O_1 remains constant:

$$M = D.B_1O_1 = S.y = constant \quad (1)$$

As a result, the angle β^0 decreases, the force Eat B_1 increases according to equation (2) and keeps the pressure of the package on the grooved drum constant during winding.

$$E = \frac{D}{\sin \beta_0} \quad (2)$$

The fabricated winding model is a similar physical model, facilitating the calculation and adjustment of winding parameters for research purposes.

Measuring the hairiness

The hairiness of the yarn before and after winding is measured according to ASTM D1425/D 1425 M - 14 (2020) by Uster tester 5. The machine has 160 channels, can also measure the evenness, imperfection... of slivers, raw yarns, yarns of all kinds. Measuring range: From 10 dtex to 2500 dtex (Nm 1000 ÷ Nm 4). Sensitivity: +/- 5% to + 500% / - 100%. Speed level: 25 to 800m/min, measuring time: from 6 seconds to 20 minutes. The hairiness measuring principle is presented in Figure 2.

At the measuring slot there is a constant monochrome parallel light source. As the yarn passes through the measuring slot, the scattered light formed from the refracted, diffracted and reflected rays of the individual fibers and the fibers protruding from the main bonding part of the yarn body is clearly seen. As a result, the hairiness is measured and displayed at the receiver and converted into the corresponding electrical signal.

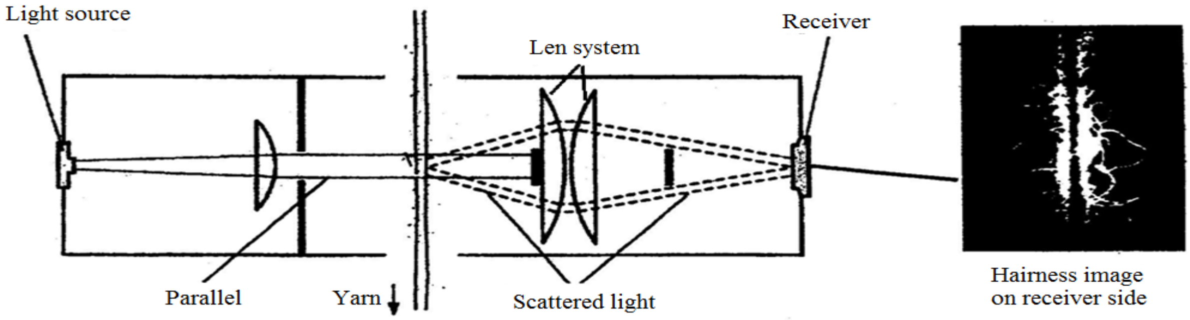

Figure 2. Hairiness measuring principle.

Table 2. Central value and variation range of winding parameters.

Parameters	**Actual values**				**Coded values**			
	Z_1 **[m/min]**	Z_2 **[cN]**	Z_3 **[cm]**	Z_4 **[N]**	x_1	x_2	x_3	x_4
Top level	1200	30	18	21	+1	+1	+1	+1
Base level Z_j^0	900	20	14	14	0	0	0	0
Bottom level	600	10	10	7	-1	-1	-1	-1
Variation range ΔZ_j	300	10	4	7	-	-	-	-

The intensity of the light on the receiver is proportional to the amount and length of fibers protruding from the yarn body. In other words, it is proportional to the hairiness. It is then converted to a digital value and evaluated by the Uster tester 5 computer. The parameters installed into the Uster tester 5 include type of test: normal, measuring slot No. 4, sample pulling speed 400m/min, measuring time 1min, environmental conditions: temperature 20 ± 20C, relative humidity 65 ± 2%.

The experimental planning method

The second-order orthogonal experimental planning method was used (BOX - WILSON planning) to establish the experimental matrix and mathematical models showing the relationship between increasing percentage of the hairiness of the yarn after winding and the selected winding parameters with the help of Excel 2019 and Design Expert 11 software.

RESULTS AND DISCUSSION

Determination of variation range of winding parameters

When winding, the winding parameters that are considered to have a great influence on the hairiness or increase in hairiness of the yarn after winding compared to before winding include: Winding speed (Z_1), the load on the friction discs of the yarn tensioner (Z_2), the distance between the bobbin and the yarn guide (Z_3) and the pressure of package on the grooved drum (Z_4). In this study, the values of winding parameters in Table 2 were selected on the basis of inheriting the studies [3,9], surveying the winding conditions of common yarns in enterprises, yarn quality before winding and the ability of the winding model.

Coding and experimental matrix establishing

The experimental regression equation of the hairiness increase of the yarn after winding for coding variables has the following general form:

$H = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{23}x_2x_3 + b_{24}x_2x_4 + b_{34}x_3x_4 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{44}x_4^2$

Where:

$b_0, b_1, b_2, b_3, b_4, b_{12}, b_{13}, b_{14}, b_{23}, b_{24}, b_{34}, b_{11}, b_{22}, b_{33}, b_{44}$: Regression coefficients

x_1, x_2, x_3, x_4: The encoding variables of winding parameters

To establish an experimental matrix, Z_j is converted to x_j according to the formula:

$$x_j = \frac{Z_j - Z_j^0}{\Delta Z_j} \quad (3)$$

Then, a full experimental table is made. The number of experiments N with the number of variables k = 4 is determined by the $N = 2^k + n_0 + 2k$ where, n_0 is the number of experiments in the center ($n_0 = 1$). So, N = 25. Coefficient $\alpha = \sqrt{\sqrt{N.2^{k-2}} - 2^{k-1}} = \sqrt{\sqrt{25.2^2} - 2^3} = 1.414$.

Experimental matrix and experimental results are shown in Table 3 in which, h_1%, h_2%, h_3%are the increasing percentage of the hairiness of three types of yarns Ne 31/1 CVCD, Ne 30/1 CVCM, Ne 30/1 COCM after winding compared to before winding determined according to each experiment. Each experiment wound 4 bobbins (each bobbin has a mass of 48g) so that the package has enough length for hairiness measurement. The increasing percentage of the hairiness (hairiness increase) of the yarns after winding is calculated by the formula:

Table 3. Experimental matrix and experimental results (k = 4; n_0 = 1).

N^0	x_0	x_1	x_2	x_3	x_4	Z_1	Z_2	Z_3	Z_4	Ne 31/1 CVCD		Ne 30/1 CVCM		Ne 30/1 COCM	
										h_1	h_1 [%]	h_2	h_2 [%]	h_3	h_3 [%]
1	+	-	-	-	-	600	10	10	7	7	24.78	7.02	26.49	7.03	23.33
2	+	+	-	-	-	1200	10	10	7	7.56	34.76	7.49	34.95	7.28	27.72
3	+	-	+	-	-	600	30	10	7	7.18	27.99	7.19	29.55	7.18	25.96
4	+	+	+	-	-	1200	30	10	7	7.48	33.33	7.44	34.05	7.4	29.82
5	+	-	-	+	-	600	10	18	7	6.99	24.60	6.95	25.23	7.23	26.84
6	+	+	-	+	-	1200	10	18	7	7.08	26.20	7.08	27.57	7.37	29.30
7	+	-	+	+	-	600	30	18	7	7.02	25.13	7.04	26.85	7.21	26.49
8	+	+	+	+	-	1200	30	18	7	7.14	27.27	7.16	29.01	7.35	28.95
9	+	-	-	-	+	600	10	10	21	6.88	22.64	6.7	20.72	6.92	21.40
10	+	+	-	-	+	1200	10	10	21	6.99	24.60	7.02	26.49	7.44	30.53
11	+	-	+	-	+	600	30	10	21	7.24	29.06	7.22	30.09	7.05	23.68
12	+	+	+	-	+	1200	30	10	21	7.3	30.12	7.23	30.27	7.33	28.60
13	+	-	-	+	+	600	10	18	21	7.32	30.48	7.26	30.81	7.09	24.39
14	+	+	-	+	+	1200	10	18	21	7.65	36.36	7.69	38.56	7.43	30.35
15	+	-	+	+	+	600	30	18	21	7.34	30.84	7.34	32.25	7.2	26.32
16	+	+	+	+	+	1200	30	18	21	7.86	40.11	7.76	39.82	7.52	31.93
17	+	0	0	0	0	900	20	14	14	7.33	30.66	7.04	27.43	7.26	27.37
18	+	α	0	0	0	1324	20	14	14	7.42	32.26	7.42	33.69	7.5	31.58
19	+	-α	0	0	0	475	20	14	14	6.94	23.71	6.91	24.50	7.01	22.98
20	+	0	α	0	0	900	34.14	14	14	7.38	31.55	7.4	33.33	7.32	28.42
21	+	0	-α	0	0	900	5.86	14	14	7.17	27.81	7.18	29.37	7.19	26.14
22	+	0	0	α	0	900	20	19.65	14	7.41	32.09	7.41	33.51	7.42	30.18
23	+	0	0	-α	0	900	20	8.34	14	7.14	27.27	7.17	29.19	7.08	24.21
24	+	0	0	0	α	900	20	14	23.9	7.34	30.84	7.34	32.25	7.15	25.44
25	+	0	0	0	-α	900	20	14	4.1	7.22	28.70	7.2	29.73	7.22	26.67

$$h_u = \frac{h - h_0}{h_0}.100\% \quad (4)$$

Where:

h_0: Hairiness of yarn before winding (determined from yarn wound on bobbins of the respective yarns in Table 1)

h: Hairiness of yarn after winding (determined from yarn wound on packages) according to each experiment of the respective yarns.

Experimental results have shown that the increasing percentage of the hairiness of all three types of yarns after winding is quite high (up to 40.11%) because when winding, the yarn is influenced by the winding parameters, so it is pulled, friction with the guides, friction discs of the tensioner, notches of grooved drum, so the number and the length of the ends fibers are pulled out of the yarn body increase, causing hairiness increase (increase in hairiness).

Establishing the regression equations

By using the Design Expert software, the regression coefficients have been calculated and tested according to Student's standards. After removing the insignificant coefficients, we get the regression equations of the following form:

$H_1 = 29.3262 + 2.4677x_1 + 1.2361x_2 + 1.0265x_3 + 1.1584x_4 + 0.7910x_2x_4 + 3.0637x_3x_4$

$R^2 = 0.8773$

$H_2 = 30.2285 + 2.5867x_1 + 1.3334x_2 + 1.1799x_3 + 0.9436x_4 + 3.1407x_3x_4$

$R^2 = 0.9184$

$H_3 = 27.1439 + 2.5464x_1 + 0.5560x_2 + 1.0972x_3 - 0.3180x_1x_2 - 0.3618x_1x_3 + 0.7785x_1x_4$

$R^2 = 0.9239$

The regression coefficients represent the influence of winding parameters on the increasing percentage of the hairiness of the yarn after winding. It can be seen that:

In the selected range, the four winding parameters: the winding speed (x_1), the load on the friction discs of the yarn tensioner (x_2), the distance between the bobbin and the yarn guide (x_3) and the pressure of package on the grooved drum (x_4) all have the effect on the hairiness increase of the yarns after winding.

In the four winding parameters selected to study the influence, the winding speed parameter (x_1) has the greatest influence on the hairiness increase of the yarn (coefficients b_1 in equations H_1, H_2, H_3 all have maximum values and are equal to 2.4677, 2.5867, 2.5464), followed by the effect of the load on the friction discs of the yarn tensioner (x_2) (coefficients b_2 equals 1.2361, 1.3334, 0.5560 in equations H_1, H_2, H_3), followed by the effect of the distance (x_3) (coefficients b_3 equals 1.0265, 1.1799, 1.0972 in equations H_1, H_2, H_3). All these three parameters have a positive influence on the hairiness increase of the yarn after winding.

To determine the influence of two parameters: winding speed (x_1) and the load on the friction discs of the tensioner (x_2) on the hairiness increase of the yarn after winding and check the reliability of mathematical models have been established,

Table 4. The hairiness increase H and the difference of the hairiness increase ∆H when the windingspeed (x_1) changes.

Real variable	Encoding variable	Yarn Ne 31/1 CVCD			Yarn Ne 30/1 CVCM			Yarn Ne 30/1 COCM		
Z_1 [m/min]	x_1	H_1	H_{1k}	ΔH_1	H_2	H_{2k}	ΔH_2	H_3	H_{3k}	ΔH_3
700	-0.6666	27.68	28.63	3.43	28.5	29.21	2.49	25.45	26.17	2.85
800	-0.3333	28.50	29.9	4.91	29.36	30.1	2.52	26.29	26.97	2.58
900	0	29.33	30.66	4.53	30.23	30.85	2.05	27.14	27.37	0.85
1000	0.3333	30.15	31.01	2.85	31.09	32.45	4.37	27.99	28.51	1.85
1200	+1	31.79	33.19	4.41	32.82	33.62	2.43	29.69	30.61	3.09

Table 5. The hairiness increase H and the difference of the hairiness increase ∆H when the load (x_2) changes.

Real variable	Encoding variable	Yarn Ne 31/1 CVCD			Yarn Ne 30/1 CVCM			Yarn Ne 30/1 COCM		
Z_2 [cN]	x_2	H_1	H_{1k}	ΔH_1	H_2	H_{2k}	ΔH_2	H_3	H_{3k}	ΔH_3
10	-1	28.09	28.46	1.31	28.89	29.31	1.45	26.59	26.8	0.80
15	-0.5	28.71	29.42	2.47	29.56	30.11	1.86	26.87	27.05	0.66
20	0	29.33	30.15	2.79	30.23	30.85	2.05	27.14	27.37	0.85
25	0.5	29.94	31.19	4.17	30.89	31.44	1.78	27.42	27.72	1.09
30	+1	30.56	31.92	4.45	31.56	32.34	2.47	27.7	28.25	1.98

calculated according to the regression equations and tested experimentally to measure the hairiness of the yarn under the conditions:

1. The winding speed x_1 changes, $x_2 = 0$ ($Z_2 = 20$ cN), $x_3 = 0$ ($Z_3 = 14$ cm), $x_4 = 0$ ($Z_4 = 14$ N).

2. The load x_2 changes, $x_1 = 0$ ($Z_1 = 900$ m/min), $x_3 = 0$ ($Z_3 = 14$ cm), $x_4 = 0$ ($Z_4 = 14$ N).

The calculation results and experimental determination of hairiness increase H (%) and ∆H (%) in Table 4 and Table 5.

Where:

x_1, x_2: The encoding variables are determined by the formula (3).

H_1, H_{1k}, H_2, H_{2k}, H_3, H_{3k}: The hairiness increase of the yarns after winding calculated according to the regression equations and determined by experiments when the winding speed x1 changes (table 3.3) and the load changes (Table 4).

ΔH_1, ΔH_2, ΔH_3: The difference of the hairiness increase of yarns after winding are determined by experiments compared with the calculation when the winding speed x_1 changes (Table 4) and the load changes (Table 5).

It can be seen that: The hairiness increase of the 3 types of yarn after winding increases with the winding speed Z_1 and the load on the friction disc of the tensioner Z2. Winding speed Z_1 increased by 71.4% (from 700 to 1200m/min), H_1 increased by 14.8% (from 27.68 to 31.79%), H_2 increased by 15.2% (from 28.5 to 32.82%), H_3 increased by 16.6% (from 25.45 to 29.69%). Load Z_2 increased by 200% (from 10 to 30cN), H1 increased by 8.8% (from 28.06 to 30.56%), H_2 increased by 9.2% (from 28.89 to 31.56%), H3 increased by 4.2% (from 26.59 to 27.7%).

The results of calculating the difference in hairiness increase according to the regression equations and determined experimentally with a deviation of less than 5%, proving that the established computational models achieve an acceptable level of confidence.

Under the same conditions of winding technology (Z_1, Z_2), the hairiness increase of the 3 yarns is not the same because they are also influenced by yarn count, yarn composition, yarn production technology and yarn hairiness before winding. The increase in hairiness of Ne 30/1 CVCM yarn was the highest among the three yarns mainly due to the lowest hairiness of this yarn before winding (Table 1).

The interplay among these four winding parameters is also shown quite clearly through the coefficients $b_{24} = 0.791$, $b_{34} = 3.0637$ (in equation H_1), $b_{34} = 3.1407$ (in equation H_2), $b_{12} = 0.3180$, $b_{13} = 0.3618$, $b_{14} = 0,7785$ (in equation H_3). Thus, when all four of these parameters change at the same time or only one of these parameters changes, the hairiness increase of the yarn after winding will change.

The value R^2 is the correlation coefficient, which indicates the error between the experimental and calculated results. As the R^2 is closer to 1, it shows that the calculated results according to the regression equations and the experimental results are very close. In this study, $R^2 = 0.873$; 0.9184; 0.9239, which shows that the calculated and experimental results are close and acceptable.

It is possible to see the image of the faces representing each relationship between the pairs of parameters of the objective function on the basis of fixing the remaining parameters at the encoding level 0 at the center through the 3D graph. Figures 3, 4, and 5 are examples.

Determination of optimal winding parameters

Inheriting the research result [4] and winding at high speed in research range to achieve high winding productivity, optimal winding parameters are determined from the point of view of achieving the required hairiness from 25 ÷ 30%.

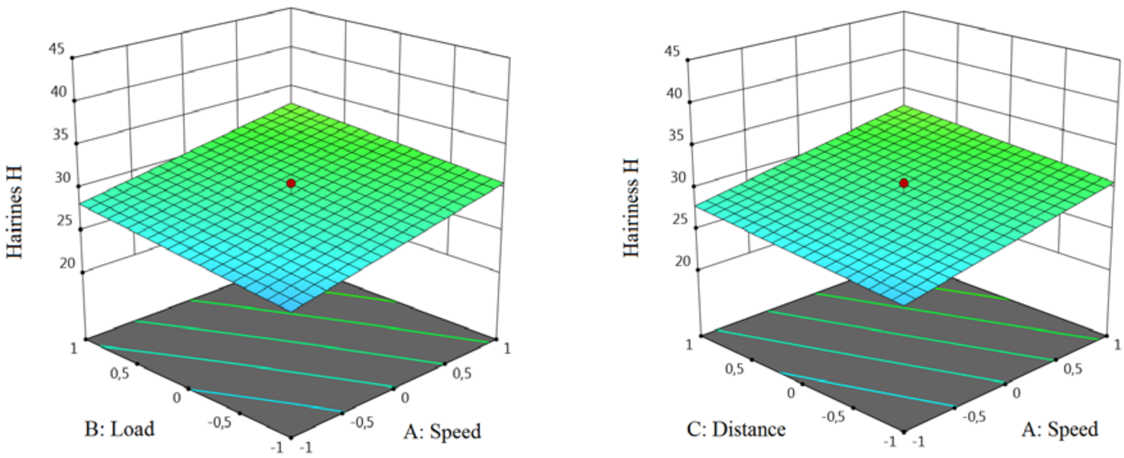

Figure 3. Yarn Ne 31/1 CVCD.

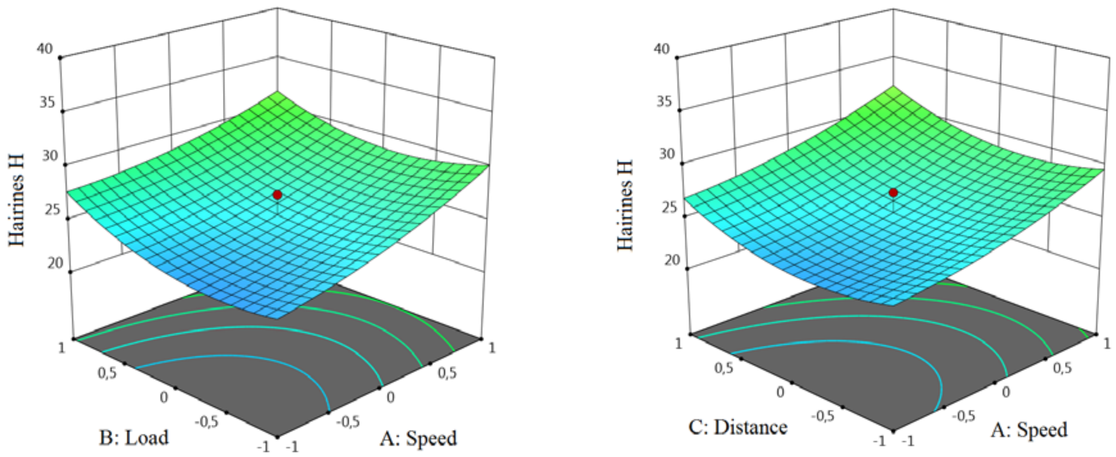

Figure 4. Yarn Ne 30/1 CVCM.

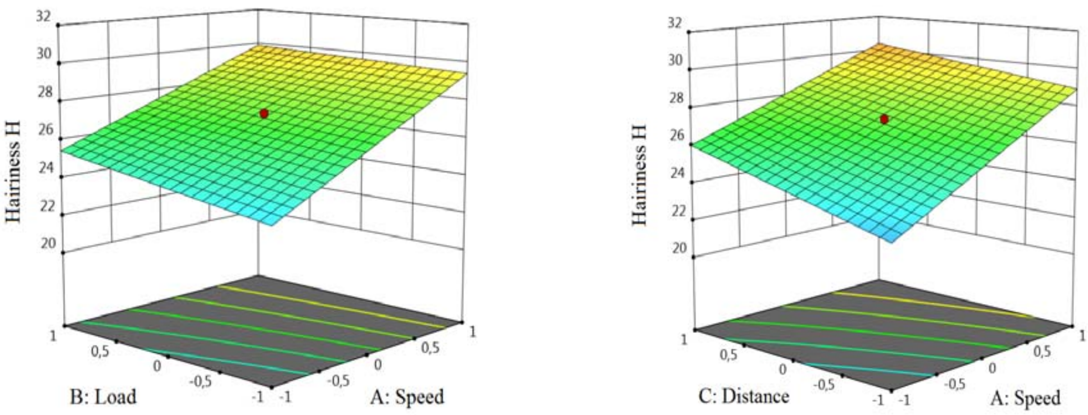

Figure 5. Yarn Ne 30/1 COCM.

However, when winding at high speed, the yarn tension is high, the breakage rate of yarn increases, the winding efficiency decreases, and the yarn hairiness increases.

To choose the optimal winding speed, an experimental study was performed in the condition of variable winding speed Z_1 = 10m/s (600m/min), 13.3m/s (800m/min), 16.6m/s (1000m/min), 20m/s (1200m/min), Z_2 = 20cN, Z_3 = 14cm, Z_4 = 14N. Winding 20 bobbins of yarns, each bobbin has a mass of m_0 = 48g, (the length is L = 1.693.Ne.m_0), monitor the breakage rate of yarn and calculate the winding efficiency taking into account the influence of the breakage rate of yarn.

Yarn Ne 31/1 CVCD, L = 2519.18 (m)

Yarn Ne 30/1 CVCM, L = 2437.9 (m)

Yarn Ne 30/1 COCM, L = 2437.9 (m)

Table 6. Results of P_0 and η when winding speed changes

Yarn	Yarn breakage P_0 (times/bobbin)	Winding speed Z_1 [m/s]			
	Winding efficiency η [%]	10	13.3	16.6	20
Yarn Ne 31/1 CVCD	P_0	0	1.3	1.5	5.0
	η	96.18	89.17	85.86	67.72
Yarn Ne 30/1 CVCM	P_0	0	1.1	1.3	4.5
	η	96.05	89.72	86.45	73.04
Yarn Ne 30/1 COCM	P_0	0	1.2	1.4	4.8
	η	96.05	89.28	85.95	71.74

Table 7. The results of determining the optimal winding parameters to achieve the required hairiness

Yarn	x_1	x_2	x_3	x_4	Z_1 [m/min]	Z_2 [cN]	Z_3 [cN]	Z_4 [N]	H [%]	h
Ne 31/1 CVCD	0.333	-1	-1	1	1000	10	10	21	25.18	7.02 ± 1.07
Ne 30/1 CVCM	0.333	-1	-1	1	1000	10	10	21	26.38	7.01 ± 1.03
Ne 30/1 COCM	0.333	-1	-1	-1	1000	10	10	7	26.30	7.19 ± 1.11

Winding efficiency η (%) is determined by the formula:

$$\eta = \frac{T_{lt}}{T_{tt}}.100 = \frac{T_{lt}}{T_{lt} + T_d}.100 \quad (5)$$

Where:

T_{lt}: Theoretical time after finish winding a bobbin,

$T_{lt} = \frac{L}{Z_1}$ (s)

T_{tt}: Actual time after finish winding a bobbin, $T_{tt} = T_{lt} + T_d$ *(s)*

T_d: Winding stop time when winding a bobbin $T_d = t(1 + P_0)$ where, t is the average splicing time at yarn break or change bobbin (t = 10s), P_0 is the average breakage rate of yarn after winding a bobbin (times/bobbin). After substituting the known parameters in (5), the formula for calculating the winding efficiency (%) is:

$$\eta = \frac{L}{L + Z_1.t(1 + P_0)}.100 \quad (6)$$

In order to achieve the high actual winding productivity, it is necessary to winding at a high speed but also achieve a high winding efficiency. Experimental results have shown that, winding at a low speed of 13.3m/s (800m/min), η = 89.17% and winding at a high speed of 20m/s (1200m/min), the low efficiency η = 67.72% will not achieve the high actual winding productivity. Therefore, with the three types of yarn in this study, winding at 16.6m/s (1000m/min) is reasonable, then the winding efficiency will be over 85%. To achieve the required increase in yarn hairiness after winding H_1 = 25.18%, H_2 = 26.38%, H_3 = 26.30%, by using the Design Expert software, the optimal winding parameters are determined in Table 7.

The parameters Z_j, x_j, H, h (Table 6, 7) are related to each other according to the formulas: $Z_j = x_j.\Delta Z_j + Z_j^0$; $h = h_0(0,01H+1)$, h_0 is the hairiness of the yarn before winding.

The experimental results verified with optimal technological parameters, the determined hairiness only deviated from the calculated ±6%. In practice, it is possible to choose the solution of determining the optimal winding technological parameters according to the hairiness requirements between the producer and the user of the yarn after winding.

CONCLUSION

From the obtained research results, the following conclusions can be drawn:

1. The four winding parameters: winding speed x_1 (Z_1), the load on the friction discs of the tensioner x_2 (Z_2), the distance between the bobbin and the yarn guide x_3 (Z_3) and the pressure of the package on the grooved drum x_4 (Z_4) all have influence on hairiness increase of yarns after winding: Ne 31/1 CVCM, Ne 30/1 CVCM, Ne 30/1 COCM. Of all, the effect of winding speed on the hairiness increase is the largest. That is expressed in coefficient b_1 has the largest value (equal to 2.4677; 2.5867; 2.5464) in the regression equations H_1, H_2, H_3. Winding speed increased, yarn friction with guides and grooved drum also increased lead to the yarn tension increased. The number of fiber ends and the length of the fiber ends being pulled outside the yarn body increases, causing the hairiness of the yarn increase.
2. The mathematical models of increase in yarn hairiness showing the relationships between hairiness increase of yarns after winding and the four selected winding parameters are determined. The research results are the basis for selecting optimal winding parameters to achieve the required hairiness increase or predict hairiness increase of the yarns before winding, contribute to reducing waste when producing yarn and orienting the use of yarn after winding. The methodology in this study can be applied to many different yarn samples, but the established hairiness regression models are only used for 3 types of yarns Ne 31/1 CVCD, Ne 30/1 CVCM, Ne 30/1 COCM because, these are experimental models, when the experimental conditions (yarn count, twist, production technology...) change, the experimental results and the regression models will also change.

3. The optimal winding parameters have been determined ensuse a winding efficiency of over 85% and the required increase in yarn hairiness after winding H_1 = 25.18% (with Ne 31/1 CVCD yarn), H_2 = 26.38% (with Ne 30/1 CVCM yarn), H_3 = 26.30% (with Ne 30/1 COCM yarn). The research method implemented can be applied to determine the optimal winding parameters from the point of view of achieving the required increase in hairiness and winding efficiency.

Acknowledgement: *This research is funded by Hanoi University of Science and Technology (HUST) under project number T2022-PC-094.*

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